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Template for Conceptual Model Construction: Model Components and Application of the Template

By Jim E. Henderson and L. Jean O'Neil

PURPOSE: This technical note reports on component categories identified for a template for conceptual model construction (template) and presents application of the template. The template for conceptual model construction is being presented in two technical notes; the first identified categories of descriptors (model construction parameters) that characterize the model (Henderson and O'Neil 2007) and this, the second note, presents the categories of components for the model. A Baltimore District study, the Middle Potomac Watershed Study, is the basis for an application of the template using the six-step model development process outlined in Henderson and O'Neil (2004).

BACKGROUND: Use of models (conceptual, ecosystem, and decision support models) in systemwide studies is expanding due to requirements for integration of model outputs and due to the emphasis on watershed and regional approaches to water resource problems. Conceptual models assist in integrating the multiple disciplines and models that were brought to bear in a systemwide study – providing for a common framework, communication, and identification of significant resources and pathways. By providing a framework for understanding the dynamics and relationships of complex systems, conceptual models are frequently an initial step in development or selection of numerical or dynamic simulation models (U.S. Army Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory 2006; Roden and Scheibe 2005).

Commonalities among the resources and processes of water resource systems have resulted in conceptual models that were developed with similar components, often at different levels of detail or quantification. The commonality of components gave rise to the idea of developing a template for conceptual model construction, providing categories of components for the user to review and identify the appropriate components for their study. For the template, sources of the categories of components are from previously reviewed and constructed models. The model construction parameters, which are being called descriptors[1], were developed from a review and synthesis of descriptors used in existing conceptual models. The present technical note documents the review and synthesis of component categories for the template.

During development of the component categories for this report, the Baltimore District began discussions on use of a conceptual model to identify potential ecosystem restoration projects for

[1] Descriptors (i.e., model construction parameters) are model uses, geographic extent, time/spatial scale, and model type/format.

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feasibility analysis, after completion of the Middle Potomac Watershed Section 905(b) Analysis or Reconnaissance Study (Recon Study), as it is usually known (U.S. Army Engineer District (USAED), Baltimore 2004). Part of the challenge faced by the Baltimore District is to view several subwatersheds in a more comprehensive manner to be able to plan restoration to obtain a systemwide response. Their need provided a good opportunity to test the template.

Scope of the Technical Note. In initiating a systemwide study, agency personnel, discipline experts, and public interests usually have different understandings and perspectives of the system (watershed, ecosystem), its problems, and potential solutions. These differing viewpoints often come together as a common understanding of the system is developed. The component categories of the template presented in the following sections can assist the study team in developing this common understanding. By considering the array of components that have been used in other conceptual models, the study team can identify system components appropriate for their topic, discuss their significance, and select components to represent their system.

The model components included in the template follow the Drivers-Stressors-Essential Ecosystem Characteristics (EEC)-Endpoint formulation recommended by Henderson and O'Neil (2004) (Figure 1). Existing conceptual models are of course not uniform or consistent in language and approach, but the commonalities are evident. The template thus serves as a tool to guide construction of a conceptual model, flexible enough to meet the needs of studies with different objectives and complexities.

The second part of this technical note is an application of the template descriptor and component categories and the six-step approach to conceptual model construction, using the Middle Potomac Watershed study.

Conceptual Model Components. The categories of components were identified by reviewing a variety of conceptual models for water resources applications, along with a limited number of non-water resource models (Henderson and O'Neil 2007); the models referenced in Henderson and O'Neil (2004); and other models recommended by reviewers. The relationship of the four components to each other is shown in Figure 1 from Henderson and O'Neil (2004). Table 1 summarizes the categories for each of the four components, and the following tables include examples for the categories.

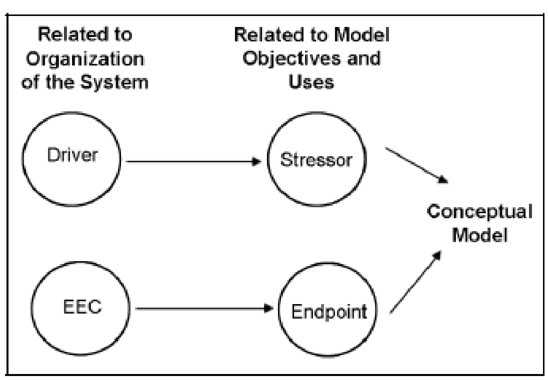

Figure 1. Relationship of the four major components of the conceptual model (Figure 10 in Henderson and O'Neil 2004)

The graphical relationships of Drivers to Stressors and of EECs to Endpoints shown in Figure 1 parallel in the similarity of categories of Drivers and Stressors (Table 1) and of examples of EEC categories and Endpoints (Table 2).

Table 1. Template Category Relationships – Drivers:Stressors

Driver Categories	Stressor Categories
Pedosphere	Landform Soil Sediment
Hydrosphere	Water Quantity Water Quality
Biosphere	Biotic Composition Biotic Structure Biotic Process
Atmosphere	Atmospheric Composition Insolation
Disturbance regime	Natural Variability Extreme Events
Socioculture	Human Phenomena and Disturbances Human Infrastructure

Table 2. Template Category Relationships – EEC:Endpoints

EEC Example	Endpoint Examples
Terrestrial Resources	Vegetative classifications, e.g., old growth pines Topographic classifications, e.g., ridges and slopes Biota – Species, population, communities Temporal and spatial distribution, e.g., migrations
Aquatic Resources	Classification, e.g., water regime, mudflat habitats Biota – Species, populations, communities Temporal and spatial distribution, e.g., fish passage
Hydrologic Resources	Water quantity Movement or flow Water quality
Chemical and Biological Resources	Nutrients Carbon Contaminants Photosynthesis
Cultural Resources	Historical properties Archaeological properties Green space Aesthetics

During the model construction process, the study team will make choices on the descriptors, e.g., how the model is to be used, and on the major factors that characterize their system. Not all models will draw on all the listed components. A targeted water management model might only

use the drivers of Hydrosphere and Socioculture, for example, focusing on changing water flow patterns with increasing watershed development. A more comprehensive system diagram may use all of the listed drivers to start the discussion. The endpoints of concern might be given, e.g., by political or legal conditions or prior public input, so the EEC step may not be perceived as necessary. However, identification of EECs as an organizational device should provide a check on the relevance and completeness of predetermined endpoints.

Even with a more limited system or one that is better understood, the study team is encouraged to assure completeness by beginning the model construction process with discussion of all four components and a range of driver and stressor categories. The team should use information from these tables and add pertinent components to get the best representation and use for their purposes.

Drivers. Changes in natural systems are the result of forces on ecosystem structure and function. For conceptual models as defined here, these forces are called drivers. Drivers are the natural and anthropogenic structures, processes, or regimes[1] that control or cause ('force') changes in environmental conditions, i.e., drivers identify the source or cause of the stressors in conceptual models (Henderson and O'Neil 2004). Drivers are an organizational device to allow the team to start a model with the "big picture" in mind. Sources of drivers may be natural or anthropogenic. The identification of drivers entails a comprehensive description of the system, identifying the structures, processes, and regimes that define the system and cause changes in system conditions. Table 3 summarizes the driver categories (column 1). Example drivers are shown for each category, derived from natural sources (column 2) and anthropogenic sources (column 3).

To identify Drivers in a system, consider the questions:

- **What are the controlling or determining forces, regimes, influences in the system?**
- **In the system, what are the sources of change? of stability?**
- **How would you organize the subsystems making up your system?**

[1] Institutions and policies (e.g. water quality standards) can also be drivers.

Table 3. Driver Categories

Categories	Natural Examples	Anthropogenic Examples
Pedosphere	Geology	Land Clearing/Vegetation Removal
	Landform	Land Use:
	Soil	Agriculture, Commercial/Industrial, Protection, Recreation
	Sediment	Residential
		Sediment Management
Hydrosphere	Surface water	Water Management - Storage, Stream flow, Water Supply
	Groundwater	Wastewater Management
	Water quality	Water Quality Management – contaminant control or release
Biosphere	Genetics	Genetically modified biota
	Plant production	Commercial production and harvest – silviculture, horticulture, agriculture
	Animal production	Commercial production and harvest – aquaculture, fisheries
	Microbial production	Recreational production and harvest – fishing, hunting, trapping, non-consumptive uses
	Biological energy flows	Fertilization and waste effluents
	Biomass production	Sediment movement
	Nutrient cycles	Pattern of land use
	Sediment mobilization and movement	
	Spatial relationships – distribution, diversity, pattern and mosaic	
Atmosphere	Sunlight	Air Pollution
	Climate Change	Climate Change
	Weather	Sea Level Change
	Insolation	
Disturbance Regime	Extreme Natural Events – fire, drought,flood, infestations	Human caused fire, floods, infestations
Socioculture		Human Populations and Demographics Human Infrastructure (for presence, use, and permanence of cultural features), e.g., housing, commerce, transportation, water delivery systems, resource extraction Systems for management of hazards, e.g., contaminants, flood reduction

Stressors. The drivers of the system set in motion flows of energy and material over time and space. Stressors are the physical, chemical, biological, and human-influenced changes that result from the drivers. These changes can be natural and modest in effect, such as Plant Production (Biosphere: Plant Production[1] and Biotic Process: Vegetation Succession), or anthropogenic and severe, such as Pedosphere: Land Use (Driver) and induced erosion (Landform: Erosion, Stressor), water quality changes (Water Quality: Composition (Stressor)), and habitat loss (Biotic Structure: Habitat Change (Stressor)). A change may not be a stressor until a threshold is met, causing a substantive transformation or effect on a significant resource or category of resources (see Essential Ecosystem Characteristics, next section).

The term stressor is used to describe these changes because the stressor changes, stresses, configures, or transforms the system. Stressor is presented as a neutral term because some changes are intended to be positive, e.g., increase in dissolved oxygen, and some are negative, e.g., an increase in invasive species. The categories of drivers and stressors show congruence, in that typical stressors can be identified by considering each of the drivers. For example, in the Upper Mississippi modeling work (Lubinski and Barko 2003), the driver of Hydrologic Regime is associated with stressors such as wetland drainage and water table alteration. The team might select salinity as a stressor and then agree that for their particular system, either high or low salinity is the focus. Vegetation succession is a natural process, but is a negative stressor on bobwhite quail populations when early succession habitats mature. Infiltration is listed as an example stressor (Water Quantity:Infiltration). The actual stressor described in a model might be reduced stormwater infiltrate. Also, when modeling a complete system, trade-offs among resources are recognized, meaning that not all resources will benefit from the same change in a particular stressor. Some of the changes in a system are within the range of natural variability, but many human actions exacerbate or change natural phenomena to unacceptable or unsustainable levels. This is further complicated by the time scale being considered, i.e., long-term versus short-term disturbances.

Table 4 summarizes stressor categories and examples. The Stressor Categories are shown in the second column, with the associated Driver Categories from Table 3 in the first column. There are several examples of interconnections and redundancies in the list. Erosion can be considered a pedospheric change, a change in substrate composition, or a water quality effect. A water diversion can be considered as either a landform or hydrologic change. Habitat changes are categorized in Table 3 as an example of the Biotic Structure category, but in some circumstances, habitat may be an endpoint, the target condition. Choices and decisions like these are left to the modeling team.

To identify stressors, consider the questions:

- **What are the causes of change in the system?**
- **Which of those changes concern our significant resources or potential endpoints?**
- **What are the physical and chemical flows of energy, material (nutrients, sediment, contaminant), or information that result in change in the system's components?**

[1] This text will use the convention Category:Example to denote Driver Categories and Examples of Drivers as well as Stressor and EEC categories and examples.

Table 4. Stressor Categories, Types of Change, and Example Stressors

Driver Category	Stressor Category	Results in Changes in:	Example Stressors
Pedosphere	Landform	Topography	Land use change Dredging Erosion Accretion Channel change Streambank change Elevated soils Water diversion Vegetation loss
	Soil	Composition	Layers removed Ponded Saline Acidic Leached Clay pan
	Sediment	Composition	Transport Scouring Erosion Accretion Smothering Pavement formation
Hydrosphere	Water Quantity	Flow	Dams Dam removal Diversions and water export Runoff from floodplain (e.g.,impervious surfaces) Impoundments Ice jams Bank stabilization
		Magnitude	Discharge Stage Extent of floodplain Storm water management Water table change
		Duration	Change in length of inundation
		Timing	Flooding cycle Recharge rate Periodicity Return period Exceedance frequency
		Movement	Infiltration Evaporation Runoff

(Sheet 1 of 3)

Table 4. (Continued)

Driver Category	Stressor Category	Results in Changes in:	Example Stressors
Hydrosphere (continued)	Water Quality	Water Quality Composition	Nutrients Sediment Contaminants Contaminated runoff Contaminated sediments Phytoplankton Dissolved oxygen pH Pesticides and herbicides Petroleum compounds
Biosphere	Biotic Composition	Fauna Flora	Species Populations Communities Abundance Diversity Richness Invasives Agriculture Tolerant species Predators Competitors Infestations Disease Physical anomalies Harvest
	Biotic Structure	Habitat or System Framework	Vegetation establishment and removal Spatial arrangement Fragmentation Barriers Connections Habitat alteration or change
	Biotic Process	Process Dynamics (Rates, Directions)	Biotic growth, extirpation and succession Nutrient production and processing Chemical processing Metabolism Vegetation succession Shading Contaminant uptake Genetic swamping
Atmosphere	Atmospheric Composition	Constituents	Air quality parameters
			(Sheet 2 of 3)

Table 4. (Continued)

Driver Category	Stressor Category	Results in Changes in:	Example Stressors
Atmosphere (continued)	Atmospheric Composition (continued)	Weather	Temperature Precipitation
		Sunlight	Shading, increased temperature
Disturbance regime	Natural variability Extreme events	Magnitude	Fire Drought Flood Wind
		Timing	Fire Drought Flood Wind
Socioculture	Human Phenomenon	Processes	Demographics and population Land use change Water use Energy use Energy production Construction Over consumption Introduction of non-native species
	Human Infrastructure	Human Support Services	Housing Industrial development Agriculture Resource extraction Transportation Hazard reduction (e.g. floodways)
			(Sheet 3 of 3)

Essential Ecosystem Characteristics (EEC). The concept of an EEC was developed to assist in organizing the system (ERDC and Harwell Gentile and Assoc. 2001), especially where the endpoints, stressor interactions, and pathways are complicated. In conceptual models, EECs are an organizational construct, like drivers, that organize the system into major components. The EECs focus all of the changes of the stressors. Conceptual models without organizing EECs can produce spaghetti-like pathways to the endpoints, and can force the user to develop their own sense of what changes produce effects on endpoints. The EECs identify the system components that produce or result in the endpoints in the system. The organizing categories reflect or respond to the model domain, the process being used for development or construction of the model, and the resources of interest (Henderson and O'Neil 2004).

Because significant resources are the focus of Corps planning, resource categories are often the identified EEC. Example system categories of EECs are (Henderson and O'Neil 2004):

- Ecosystem processes (Lubinski and Barko 2003), or functions.
- Resource categories, e.g., terrestrial resources, aquatic resources.

- Categories or classifications of ecosystems, based on for instance, topography and water regime (e.g., the subregions included in the Fire Island to Montauk Point study (ERDC and Harwell Gentile and Assoc. 2001)).

Identifying readily recognized or significant resources as the EEC can give a focus to model users and stakeholders from a range of backgrounds. For instance the question, "what happens to nutrients" could be answered by looking at a Biogeochemistry EEC (Lubinski and Barko 2003) that identifies the drivers affecting biogeochemical changes, and identifies the nutrients or other endpoints that result from biogeochemical processing. Examining relationships of the Biogeochemistry EEC to stressors and endpoints is more straightforward and efficient than asking a user to trace out all the nutrient transformations that lead to an endpoint. With a Habitat EEC, stakeholders can determine that a sensitive ecosystem (endpoint) will be affected through the vegetative, sediment, and hydrologic stressors, integrated by the Habitat EEC.

Sometimes the Stressor-Endpoint relationship is not complex, e.g., a single stressor producing a single endpoint and EECs is not needed to organize numerous stressors or to clarify relationships. As a simple example, consider installation of retention ponds and realignment of runoff patterns to improve groundwater infiltration, increase riparian habitat, and reduce detritus input to streams. It is easy to think of many other changes (e.g., vegetative) that could accompany these development actions. The endpoints are processed through groundwater and soil resources, riparian resources, and in-channel resources – the EECs of the model. Changes in endpoints of groundwater levels, aquatic habitat, and nutrient levels (detritus) in the water are readily understood as occurring within different components of the system. With the EECs in place, it is easy to envision or measure what happens if flows are increased or if there is dumping of pollutants in the runoff. The EECs assist in tracing the effects of changed levels of stressors or drivers through the system, helping to identify the resources that will or will not be affected, and to expedite determining how endpoints are or are not affected.

The EEC categories shown in Table 5 demonstrate different types of EECs, responding to different systems. The table includes the ecosystem processes used in the Upper Mississippi River Conceptual Models (Lubinski and Barko 2003), a general resource organization (Resource Categories), the Ecosystem Categories used in the Fire Island to Montauk Conceptual Model (USAERDC and Harwell, Gentile Assoc. 2001), and Structure and Function categories.

Table 5. Different Types of EECs Responding to Different Systems

EEC Categories	EEC Examples
Ecosystem Processes - Upper Miss. River Conceptual Model EECs (Lubinski and Barko 2003)	Geomorphology Hydrology/Hydraulics Biogeochemistry Habitat Biota
Resource Categories	Terrestrial resources Aquatic resources Hydrologic resources Chemical and biochemical resources Cultural resources

(Continued)

Table 5. (Concluded)	
EEC Categories	**EEC Examples**
Ecosystem Categories (USAERDC and Harwell Gentile and Assoc. 2001)	Coastal marine ecosystems Marine offshore Marine nearshore Ocean sand and rocky intertidal Barrier island ecosystems Ocean sandy beach Ocean rocky beach Dunes and swales Maritime forests Salt marshes Bay intertidal Bay habitats Bay subtidal habitats Sand shoals and bare sand Mud flats Back barrier marsh and marsh islands Dredged material disposal islands Inlets Tidal creeks and deltas Upland ecosystems Upland terrestrial Coastal ponds
Structure	Species, population, community Landscape pattern Region, ecosystem, or subcomponents Trophic organization
Functions	
Wetland Functions (USAE ERDC 2006)	Short-term surface water storage Long-term surface water storage Maintenance of high water table Transformation and cycling of elements Retention, removal of dissolved substances Accumulation of peat Accumulation/retention of inorganic sediment Maintenance of characteristic plant communities Maintenance of characteristic energy flow
Riparian Functions (National Research Council 2002)	Hydrology and sediment dynamics Biogeochemical and nutrient cycling Habitat and food web maintenance

Endpoints. Interest in systems and management of systems is often manifested through concern for discrete system products, outputs, or conditions. Minimum flows, species extinction, aquifer recharge, and shoreline loss are conditions that have required understanding of system cause-effect relationships to enable a common understanding of the appropriate management actions and identify the responsible agencies. These resulting conditions are known as endpoints, that is, the endpoints of system functioning. Table 6 taken from Henderson and O'Neil (2004) illustrates the diversity of endpoints found in different models including the level of detail that is used. For example, the plant communities in Thomas et al. (2001) can be further defined based on significance and result in identification of specific scarce communities. The changes caused by the drivers and stressors, focused through EECs, result in endpoints (Lubinski and Barko 2003). Endpoints are quantifiable, ecologically significant, and important to public welfare. Table 7 summarizes endpoint categories and example endpoints, corresponding to potential EEC categories. The endpoint examples are listed without their quantitative metric, i.e., the units or parameter of the endpoint measured.

Table 6. Endpoint Examples

Prairie Cluster Monitoring Plan (Thomas et al. 2001)	Lake Okeechobee (Havens 1999)	EPA Ecological Risk Assessment on Terrestrial Ecosystem (Suter 1996)
Grassland plant communities	Lake water quality	Wildlife species
Woodland plant communities	Fish and aquatic fauna	Threatened and endangered species
Grassland bird communities	Native vegetation mosaic	Plant species
Rare species populations	Snail kite, wading birds, and waterfowl	Pest populations

Looking at the Endpoint Categories (Table 7), the Endpoint Examples in Table 6 correspond as follows: the Prairie Cluster Monitoring Plan (Thomas et al. 2001) endpoints are examples of the Category Terrestrial Resources: Biota – Species, populations, communities. The Lake Okeechobee endpoints (Havens 1999) are examples of Hydrologic Resources: Water Quality, and Terrestrial Resources: Biota. The EPA Ecological Risk Assessment (Suter 1996) endpoints are examples of the Endpoint Category Terrestrial Resources: Biota.

Endpoints are sometimes not measured directly, due to complexity of the endpoint and other reasons, and so indicators, assessment endpoints, or other constructs are then measured as representative of the endpoint. Table 8 identifies the endpoints and their indicators identified for the Environmental Implications portion of the National Shoreline Management Study (Henderson et al., in preparation).

Table 7. Endpoint Categories

EEC Category	Endpoint Categories	Endpoint Examples
Ecosystem Processes – Upper Miss. River Conceptual Model EECs (Lubinski and Barko 2003)	Geomorphology[1]	Topographic connections[2] Topographic variability Rates of bank erosion
	Hydrology/Hydraulics	Water level below dams Water level during growing season Pool stage during winter
	Biogeochemistry	Water quality criteria Nutrient concentrations in water Contaminated sediments
	Habitat	Aquatic vegetation in shallow lentic waters Natural terrestrial habitat on floodplain Islands with natural habitat
	Biota	Abundance of Asian carp Population of lake sturgeon Abundance of waterfowl Freshwater mussel populations Mast tree populations
Resource Categories		
Terrestrial Resources	Vegetative classifications	Upland forest
	Topographic classifications	Riparian, Floodplain, Upland
	Biota – Species, populations, communities	Mammal, Avian, Invertebrate, Special Status Species
	Temporal and spatial distribution	Vegetation mosaic and diversity (Ogden and Davis 1999)
Aquatic Resources	Classification – Water regime, habitats Biota – Species, population, communities	Marine Estuarine Influenced Wetland (Emergent Wetland) Fresh (Riverine, Impounded) Species, Populations, Communities of Fish, Invertebrates, Submerged Aquatic Vegetation
	Temporal and spatial distribution	Pool / Riffle complex
Hydrologic Resources	Water Quantity	Flow
		Magnitude
		Duration
		Timing
	Movement	Evaporation, infiltration, runoff
	Water Quality	Water quality constituents
Chemical and Biochemical Resources	Nutrients	Phosphorous, Nitrogen
	Carbon	Carbon Dioxide, Sequestered carbon

(Continued)

[1] In the Upper Miss. Conceptual model, endpoints were developed for each of the EECs, so that the Endpoint Categories are the same as the EEC (Table 5).
[2] Not all of the endpoints identified in Lubinski and Barko (2003) are listed; Table 7 is for illustration only.

Table 7. (Concluded)

EEC Category	Endpoint Categories	Endpoint Examples
Resource Categories (Continued)		
Chemical and Biochemical Resources (continued)	Contaminants	DDT
	Photosynthesis	Chlorophyll concentrations
Cultural resources	Historic properties	National Register Properties
	Archaeological sites	
	Green space	
	Aesthetics	
Ecosystem Services		
Water Cycling	Infiltration	Infiltration rates
Water Purification	Nutrient, chemical, contaminants, clarity	Nitrogen dioxide reduction rates
Stormwater Management	Quantity, retention time	Retention capacity
Air Purification	Air quality	Air clarity, pollution measures
Climate Regulation	Heat island mitigation	Temperature effects
Soil And Sediment	Sediment movement	Sediment load
Erosion Regulation	Stabilized floodplain, streambank, channels	Stream miles stabilized
Pollination	Abundance of pollution sources	Natural, artificial
Nutrient Cycling	Nitrogen, phosphorous	Standards, thresholds
Biodiversity Maintenance	Diversity	Species, populations, communities
Genetic Storage	Genetic diversity	Genetic measurements
Aesthetics	Visual resources	Visual impact assessment measures
Recreation	Recreation resources	Facilities, access, demand

Table 8. Endpoints and Indicators for Environmental Implications of Shoreline Change (Henderson et al. (2006) (draft))

Endpoint Categories	Indicators
Ecological Resources	Change in sensitive, significant, or potentially affected Land Use Land Cover categories due to erosion and accretion
	Number or percent of protected species affected by erosion and accretion
	Habitat for important species affected by erosion and accretion
Cultural/Archeological/Aesthetic Resources	Protected Cultural, Archeological, and Aesthetic Resources at risk of erosion and accretion
Social/Economic Resources	Recreation Resources – Change in presence/absence, access, and use of recreation resources due to erosion and accretion

(Continued)

Table 8. (Concluded)	
Endpoint Categories	**Indicators**
Infrastructure Resources	Number of human communities with development guidelines in place to minimize the environmental and economic effects of erosion and accretion
	Evaluation of existing and planned infrastructure in terms of non-structural approach and beneficial environmental processes (e.g., sand movement)
	Infrastructure disruption (e.g., exposed bridge abutments, pipeline exposures)
	Percent of shoreline hardened to reduce the risk of erosion
Special Status Resources	Number of National Parks, Wildlife Refuges, Marine Protected Areas, or special aquatic sites at risk of erosion and accretion
	Environmental concerns for identified erosional hotspots (acute erosion)

APPLICATION OF THE TEMPLATE AND CONCEPTUAL MODEL CONSTRUCTION PROCESS: The Middle Potomac Watershed Study (U.S. Army Engineer District, Baltimore 2004) provided an opportunity to apply the conceptual model descriptors, components, and development process to a Corps watershed study. The Middle Potomac Watershed (Section 905(b)) Analysis was completed in 2004. Restoration of water quality in the Chesapeake Bay and the Potomac's contributions to the restoration, are prominent considerations for any actions in the Middle Potomac Watershed. The Recon Study assessed conditions and identified problems and opportunities for the seven subwatersheds making up the Middle Potomac. As feasibility studies began to be funded, the need to identify specific ecosystem restoration projects became apparent. The Recon Study process did not identify ecosystem restoration projects at a level for feasibility phase analysis. To meet this need, a process was developed. The Middle Potomac Conceptual Model was constructed by ERDC, using the Recon Study and analysis, and discussions with the District. The Middle Potomac CM was used to develop a CM for one of the subwatersheds, Cameron Run. Potential ecosystem restoration projects were identified for the Cameron Run watershed, based on the CM and assessment information from the Recon Study.

This application is based on the following:

- Six-step process for development of conceptual models (Henderson and O'Neil (2004))
  - Step 1: Identify the objectives and uses of the model.
  - Step 2: Delineate the spatial and temporal scales or boundaries of the model.
  - Step 3: Identify the structural components of the system.
  - Step 4: Identify the sources of change in the system.
  - Step 5: Review the model.
  - Step 6: Implement the model.
- Conceptual model descriptor categories for model construction parameters (Henderson and O'Neil 2007).
- Conceptual model component categories - (above in this technical note).
- Information in the Recon Study and other available information.

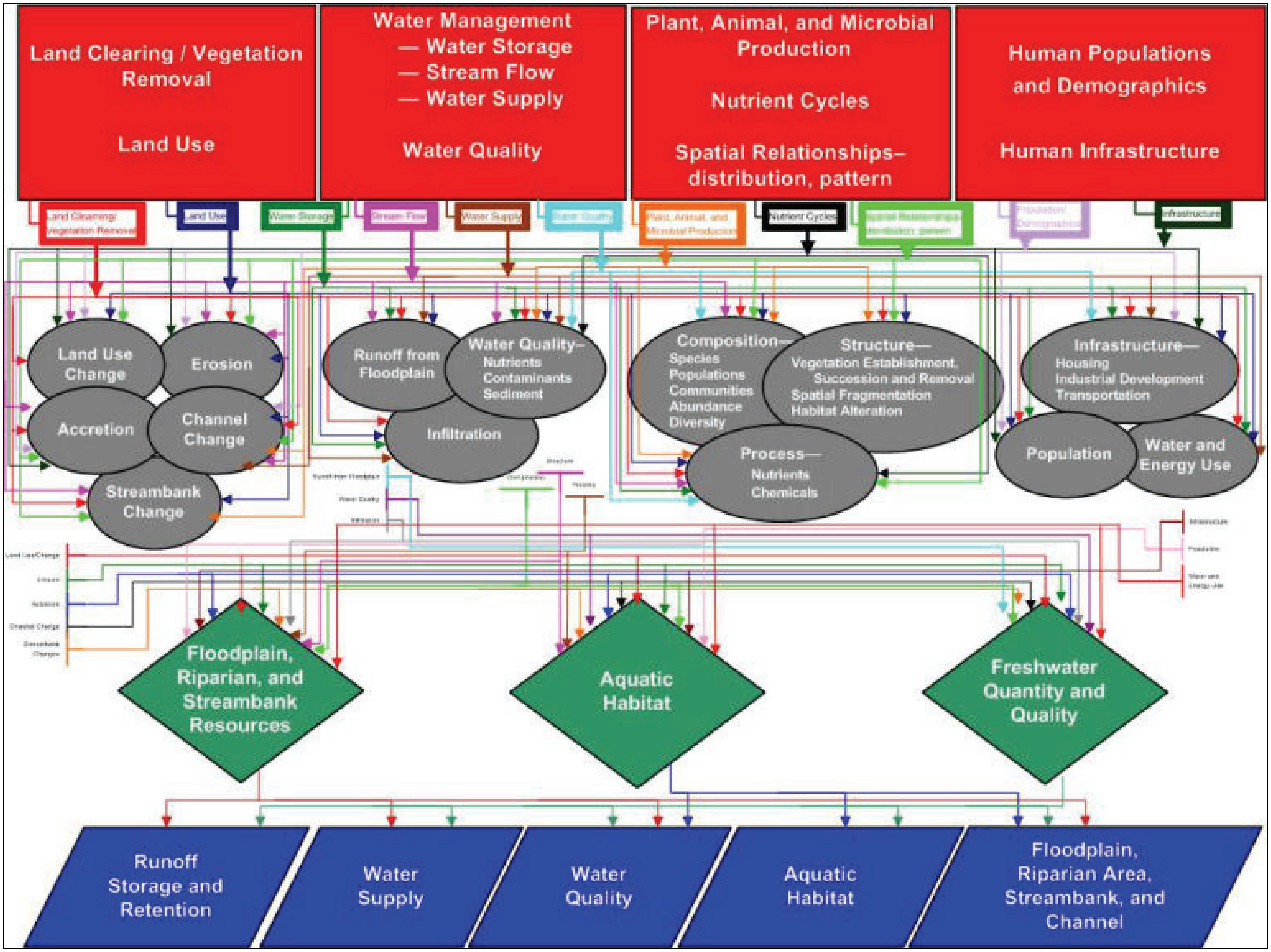

Figure 2. Middle Potomac Watershed Conceptual Model

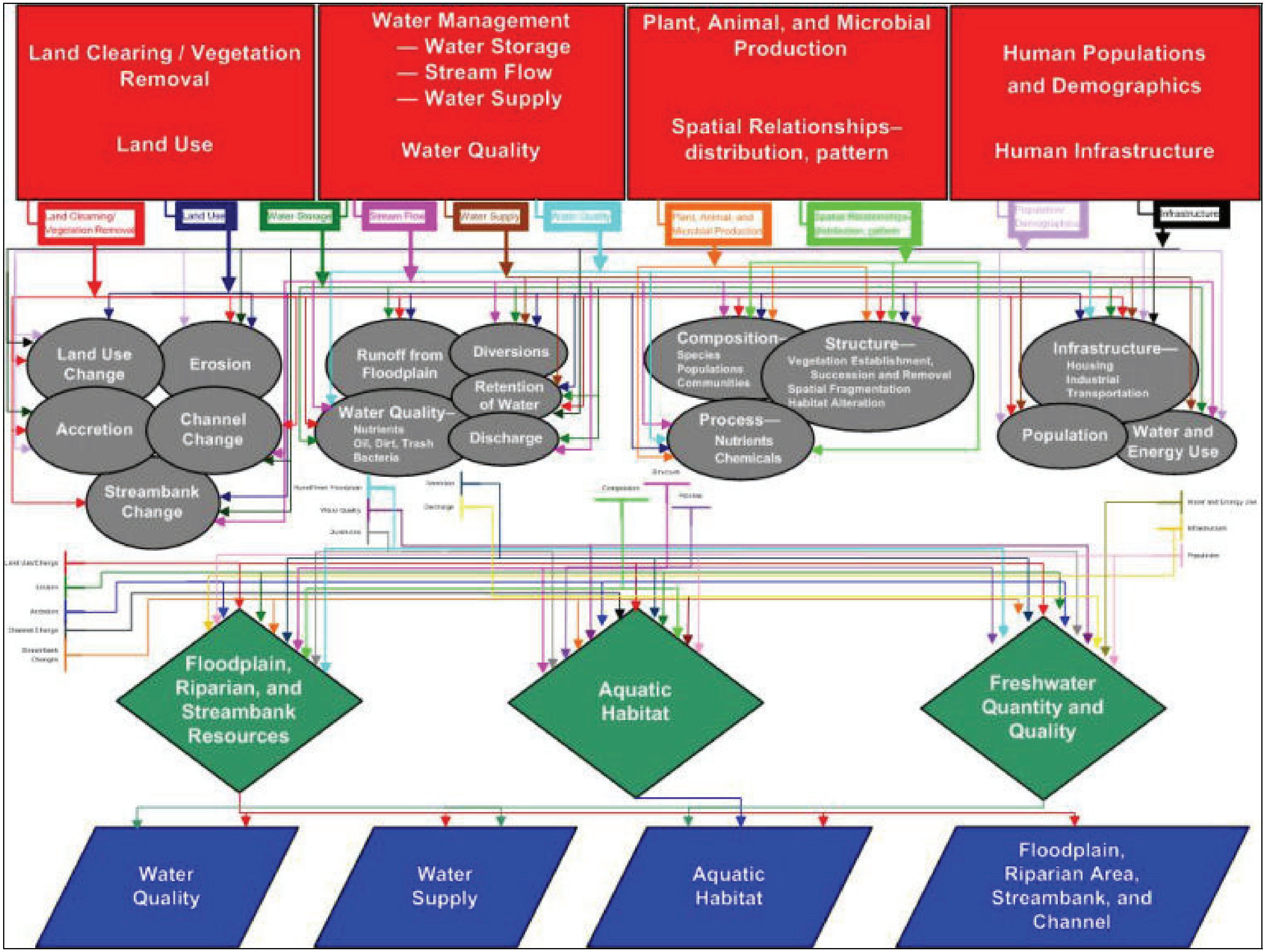

Figure 3. Cameron Run Conceptual Model

Step 1: Identify the Objectives and Uses of the Model. The objective is to organize the components of the Middle Potomac Watershed so that the conceptual model represents problems and opportunities of the entire watershed, and can be used as the basis for the CM for the subwatersheds making up the Middle Potomac. The Middle Potomac Watershed Model identifies the relationship between the watershed objectives, watershed resources, and human uses of the watershed. Cause and effect relationships are identified between the changes in the system and the watershed endpoints. Subwatershed models will be produced by using the watershed model to identify the relevant objectives, resources, and human uses in the subwatershed. The objectives for the watershed will be used to evaluate the subwatershed resource conditions, problems, and opportunities. In this way the subwatershed models will include the objectives and resources that are relevant to the subwatershed.

The model serves as the organizational framework for identifying ecosystem restoration projects at the subwatershed level. That is, the Potomac model portrays conditions for the total watershed, communicating the findings of the Recon Study. Problems and opportunities for the watershed will continue to be through identified planning and projects focused at the subwatershed level. First, water quality problems and opportunities were addressed by establishment of water quality limits for nutrients, sediments, and loading caps for subwatersheds (Commonwealth of Virginia 2005). Second, the Recon Study identified 14 feasibility studies to evaluate and recommend projects for construction. The feasibility studies are organized based on subwatershed or lessor scopes, responding to geographic proximity of problems and funding responsibilities by cost sharers.

Projects for feasibility evaluation are often identified during the initial stages of planning or in the meetings and review of the Reconnaissance Report. For the flood protection and related projects, some projects are identified for consideration in the feasibility stage; this was not the case for ecosystem restoration projects. The process for identification of ecosystem restoration projects is:

1. Construct subwatershed model –The watershed CM was used to identify the relevant drivers, stressors, EECs, and endpoints that are significant for the subwatershed. Figure 3 is the CM developed for Cameron Run, a subwatershed of the Middle Potomac. Using subwatershed information from the Recon Study (USAED Baltimore 2004), problems, opportunities, significant resources, and constraints were identified and compared to the Potomac watershed CM. Based on this analysis, drivers, stressors, EECs, and endpoints were identified for the Cameron Run Watershed.
2. Identification of restoration projects – Potential ecosystem restoration projects are identified by looking at the model and asking, “What would it take to improve or obtain the endpoints?” Table 9 shows the relationship between topics for objectives or model endpoints and ecosystem restoration projects

Table 9. Relationship of Endpoints and Ecosystem Projects

Endpoints	Ecosystem Projects
Runoff storage, retention	Wetland Restoration and Creation
Stabilized riparian, streambank, and floodplain areas	Riparian Buffer Establishment
Aquatic habitat	Channel Restoration

Step 1: Recap

Objective: Conceptual model to identify cause-effect relationships and organize system components for the Middle Potomac Watershed.
Uses: Provide organizational framework to develop subwatershed conceptual models and to identify ecosystem restoration projects for the subwatersheds.

Step 2: Delineate the Spatial and Temporal Scales or Boundaries of the Model

Step 2 addresses the Geographic Extent and the Time/Spatial Scale descriptors (Henderson and O'Neil 2007). The following questions from Henderson and O'Neil (2004) assist in clarifying the spatial and temporal boundaries. Generally, the watershed and subwatershed define the spatial scale for the model effort. Temporally, ecosystem restoration projects are planned for a 50-year project life, though this may vary by project.

At what system level are we interested? The conceptual model is developed at two spatial levels, the watershed and subwatershed levels. The Middle Potomac Watershed encompasses 11,500 sq miles; the entire Potomac River watershed is 14,697 sq miles. The seven subwatersheds within the Middle Potomac vary in size between Rock Creek (60 sq miles) and Shennandoah (3,063 sq miles).

What are the requirements in the spatial extent of the system? Spatial requirements are based on the subwatershed organization for the model.

Is the system homogeneous or are there major subdivisions of the system? The feasibility studies organized along the hydrological subwatersheds impose an assumption that sources of change and resulting outcomes differ depending on the hydrological location. The homogeneity of the subwatersheds is artificial, based on the organization of the feasibility studies, which respond more to geographic location and cost sharing than to sources of natural and anthropogenic changes in the system. A more appropriate watershed distinction may be rural versus urban or developed versus undeveloped for watershed model organization.

What are the limits to the applicability of the model? As described, organization of the subwatershed models and the identified ecosystem projects apply only to the subwatershed. After projects are identified for a subwatershed, conditions in adjoining watersheds or adjacent watersheds could be examined to see if economies of scale or dependencies indicate that the project boundary should be extended into another subwatershed.

Does the model address a single existing or hypothetical point in time or is the model to be used for evaluating future conditions? The Middle Potomac Watershed and Cameron Run models represent conditions at the time of Recon Study completion, 2004. Ecosystem restoration projects are planned for a 50-year project life, so that the components of the models must be viable over that time period. Incorporating sustainability in project planning may require flexibility and changes in the usual 50-year project life determination as the Corps works to implement sustainability and the other environmental operating principles.

Step 2: Recap

Geographic Extent: The Middle Potomac and subwatershed models are landscape level models.

Spatial Boundaries: The spatial boundaries are the watershed and subwatershed limits. In some cases, as identified above, affected adjacent or adjoining areas may be included in the model.

Temporal Boundaries: The models are developed to project changes and uses over the life of the ecosystem restoration project, assumed to be 50 years.

Step 3: Identify the Structural Components of the System. Knowing the spatial and temporal boundaries helps circumscribe the system and focus on components relevant to the model. Prior to identifying structural components, the type/format is decided. Decisions on model format – Word/Picture, Influence System Graph, Index, or Numerical – are based on model objectives and uses, type of data available and other considerations. For this application, the Influence System Graph format is selected because of the need to show flows between drivers, stressors, EECs, and endpoints.

Identifying the structural components of the system is an iterative process, but the question "where to start" always comes up. When different disciplines are grappling with their interrelationships, understanding the forces creating the system, i.e., Drivers may be the place to start. For Corps projects focused on outputs – dredging, ecosystem restoration, water control--interest is usually in obtaining a project objective or authorized output. In these cases, looking at significant resources and the desired endpoints makes more sense. In the case of the Middle Potomac Watershed, the identified significant resources, problems and opportunities lead to a set of desired outcomes for the watershed. Though representing the system components is, to a degree, intuitive, it helps to have a series of questions on which to focus the effort. The following questions are suggested by Henderson and O'Neil (2004).

What is the target condition or conditions? Planning and management of natural resources requires understanding and consensus on the desired system outcomes, an articulation of the desired system conditions. Part of the Recon Study effort is to understand the system and, additionally, to identify the desired end results. These end results in CM terminology are called endpoints, the ecosystem structures or functions that are considered ecologically significant and important to the public (USAERDC and Harwell, Gentile Assoc. 2001) welfare. Endpoints should be quantifiable and are often used in change assessment and monitoring. Down the road, when asked if the system has improved or degraded, endpoints are the structures and functions that will be examined and measured to answer that question. Goals and objectives of a study or project are not always the same as the endpoints, though the goals and objectives give insight on desired outcomes.

Restoration of the Middle Potomac Watershed sounds like a worthy endeavor, but what exactly does restoration entail? What are the endpoints, the desired conditions that are achievable and sustainable? Are restoration actions the same in each subwatershed? These questions are answered by the endpoints and relationships to stressors and drivers, and application of the CM to the subwatersheds. The Corps planning process helps in identifying endpoints through the determination of significant resources (Headquarters, U.S. Army Corps of Engineers 2000).

Significant Resources

Reviewing the Middle Potomac Watershed Study in terms of the Corps' planning process, three significant resources can be identified:

- Floodplain, Riparian, and Streambank Resources.
- Aquatic Habitat.
- Freshwater Quantity and Quality.

From the above discussion on EECs, it should be clear that these significant resources serve to organize the significant changes in the system, and so they are the EECs.

Restoration Goals and Objectives
Three restoration goals are proposed for ecosystem restoration of the Middle Potomac:

1. Modify or minimize the extremes of hydrologic dynamics, such as reducing the flashiness of runoff events, returning toward natural hydrology to the extent possible.
2. Restore water quality.
3. Restore or create aquatic ecosystem habitat.

From the analysis in the Recon Study, five endpoints can be identified as follows and shown in Figure 4:

1. Runoff storage and retention management measures to promote groundwater infiltration.
2. Water supply to meet future demand.
3. Water quality to meet requirements of the Tributary Strategies and Chesapeake Bay Program.
4. Aquatic habitat with structure to provide cover, reproductive, and feeding habitat for aquatic species- structure to include stable bottom and vegetation.
5. Floodplain, riparian area, streambank, and channel areas that are stabilized.

Figure 4. Endpoints identified for the Middle Potomac Watershed Conceptual Model

What forces or drivers form the Middle Potomac Watershed Ecosystem? Development of the States' Tributary Strategies has focused attention on water quality since completion of the Recon Study, so it is beneficial to take a broader view of the processes, regimes, or forces that determine the state of the watershed. CM construction looks at the broad categories of natural and anthropogenic drivers of ecosystems. As documented in the Recon Study, the human and natural character of the Middle Potomac ecosystem is formed, influenced, or affected by the following Drivers from Table 2:

Driver Category: Pedosphere

- *Driver: Land Clearing/Vegetation Removal.* Use of land for residential or commercial purposes requires, in almost all cases, clearing the land for access and removal of native vegetation for construction activities.
- *Driver: Land Use.* Some degree of urbanization has been occurring in all subwatersheds, except perhaps the Shenandoah. The conversion of agricultural, forested, and undeveloped lands to commercial and residential uses causes the loss of green and natural space, and an increase in impervious surfaces. These land use changes alter the amounts of landforms (e.g., wetlands) and landcover (e.g., forested buffer), replacing them with residential and commercial properties with impervious or commercially landscaped landcover.

Driver Category: Hydrosphere

- *Driver: Water Management – Storage*. The tributaries of the Middle Potomac River incorporate numerous dams, public and private, storing water for consumption and recreation. These structures alter instream flows, create deeper and pooled water conditions, and, in some cases, result in fish blockages (USACE Baltimore 2004).
- *Driver: Water Management – Stream Flow*. Middle Potomac stream flow is affected by runoff and water retention in the watershed. Changes in runoff patterns, e.g. increases from impervious surfaces, alter the historic stream flow patterns. Water storage structures and institutional operating commitments are anthropogenic determinants of stream flow.
- *Driver: Water Management – Water Supply*. The communities along the river rely heavily on withdrawal of water from the Middle Potomac for residential and commercial water supply (USACE Baltimore 2004). The reduction of natural surface and increase in imperviousness area leads to concentration of runoff, reduced infiltration, and greater amounts of suspended sediment reaching the channel.
- *Driver: Water Quality*. In the Middle Potomac, water quality has been severely impacted from pollution, sediment, and contaminants in the runoff from agricultural, residential, and commercial uses. The Chesapeake Bay Agreement established procedures to address water quality through the Tributary Strategies, the nutrient and sediment loading caps for the subbasins (Commonwealth of Virginia 2005).

Driver Category: Biosphere

- *Drivers: Plant, animal, and microbial production.* Plant, animal, and microbial production are responsible for the flora and fauna of the system. The number and abundance of native species have been negatively impacted (National Biological Information Infrastructure (NBII) 2003).
- *Driver: Nutrient cycles*. Biological production, natural and anthropogenic (e.g., agriculture), contributes to the nutrients required for system functioning, but production of excessive amounts of nutrients have surpassed the system's capacity for nutrient processing (Commonwealth of Virginia 2005).

- *Driver: Spatial relationships*. Development in the Potomac watershed has resulted in loss of continuity of resources and vegetative and landform connectiveness, resulting in fragmentation and patchiness of vegetation and land uses.

Driver Category: Socioculture

- *Driver: Human Populations and Demographics*. Development of urban and suburban areas continues so that the population of the watershed continues to increase; population is projected to increase by 14 percent between 2000 and 2020 (USACE Baltimore 2004).
- *Driver: Human Infrastructure.* The need for roads, schools, transportation and other infrastructure will cause depletion, degradation, and increased demand on natural resources – habitat, water quality, and water supply. As populations increase, need for infrastructure also increases.

Drivers for the Middle Potomac CM. Looking at categories of drivers (Table 2), the above identified influences and forces point to the Drivers identified in Figure 5. These drivers reflect the analysis in the Recon Study and other information as the forces that configure and cause changes in the Middle Potomac Watershed (Figure 2).

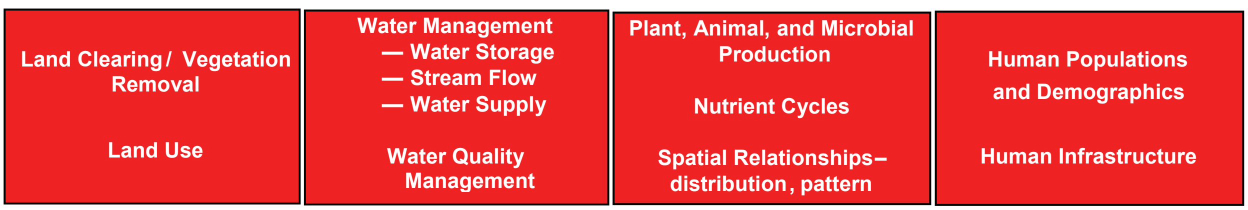

Figure 5. Drivers for the Middle Potomac Conceptual Model

What are the relationships, interactions, and processes affecting the target conditions? If drivers are the forces controlling the system and endpoints are the result of system functioning, the missing information includes "what changes occur?" and "how are all the changes organized?" Changes come to the system in the form of the stressors, that is the flows of energy, materials, and information (Table 3) proceeding from the drivers (Table 2). The changes identified are alterations of the Stressor categories Landform and Sediment; Water Quantity and Water Quality; Biotic Structure and Biotic Process; and Human Phenomenon and Human Infrastructure. Middle Potomac stressors are shown in Figure 6.

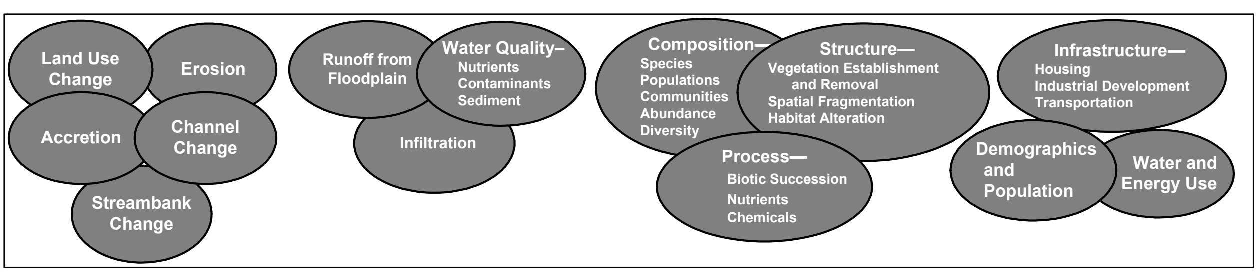

Figure 6. Stressors for the Middle Potomac Watershed Conceptual Model

How should the changes be organized, i.e., what are the EECs? Many conceptual models have numerous stressors resulting in a few endpoints. Changes in systems flows of energy (e.g., solar, metabolism), materials (e.g., elements, nutrients), and information (e.g., DNA) are assimilated and processed together in structures such as plants and animals, with distinctive individual and corporate identities, serving to organize the stressor changes to produce the endpoints. EECs are devices used to organize changes and serve as a framework for understanding and processing them. The three significant resources identified above are the focus of all the stressor changes. For the Middle Potomac, the organizing EECs (Figure 7) are types of three Resource Categories (Table 4).

- Terrestrial resources –Floodplain, Riparian, and Streambank Resources.
- Aquatic resources – Aquatic Habitat.
- Hydrologic resources – Freshwater Quantity and Quality.

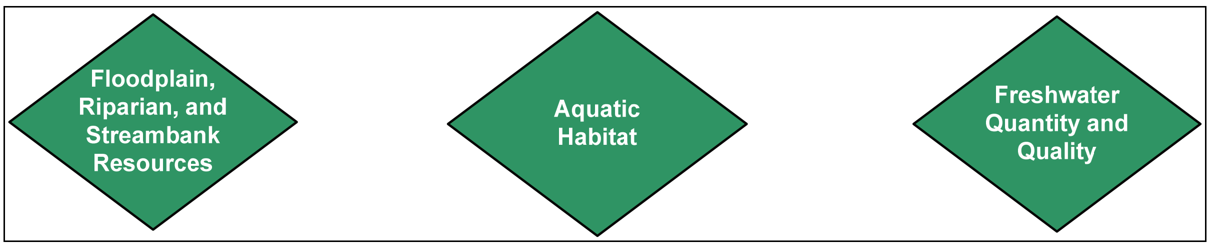

Figure 7. EECs for the Middle Potomac Watershed

Step 4: Identify the Sources of Change in the System. Sources of change in the Middle Potomac are the landform and sediment, water, biotic condition, and human development changes resulting in the endpoint conditions. This step in the CM Process can be redundant of the identification of stressors, but it is included to force the study team to identify potential change scenarios (e.g., increase in drinking water demand or change in population projections). The purpose of including the step here is to pose the question "will the model as configured (in this case, Figure 2) enable us to answer the questions for the use of the model?" Sources of change can be identified by working back through the stressors from the endpoints to the drivers; alternatively, the process can start with the drivers and work forward. In this latter case, drivers are selected and changes are followed in detail through to the endpoints. This process can be assisted through use of interaction matrices, checklists, or other tools to force consideration of potential interactions, strength of relationships, and significance. Appendix A contains example interaction matrices developed for the simplified models of the Middle Potomac and Cameron Run. The resulting pathways of change can be examined to determine whether all components are included. For instance, if identified stressors do not relate to endpoints, the stressors are likely not significant, or perhaps misrepresented. If a number of stressors link to the same endpoints, combining stressors or endpoints should be considered.

Step 5: Review the Model. It is expected that a model will undergo some refinement and revision as more information is available and model relationships are defined or disproved. To review the model, instead of considering all the pathways shown in Figures 2 and 3, it may be helpful to look at a less detailed conceptual model, such as the example in Appendix A.

Initially, the model should be reviewed after construction with these questions in mind:

- Does the model fulfill its stated objectives? The Middle Potomac model (Figure 2) establishes cause-and-effect relationships and organizes the system components for the stated use, which is to develop subwatershed models to identify ecosystem restoration projects (Step 6).
- Does the system appear complete, or is it lacking in some part? The system is complete with regard to its intended use. One could ask, in light of the efforts put into the Tributary Strategies, "where's the water quality infrastructure?" Water quality is a part of the ecosystem restoration process, and for this model its place is as an integrated part of the system model. If the objective of the model was to understand how the system would be operated, there might be EECs named flood damage reduction, water quality, and habitat.
- Can all the relationships be verified to be consistent with existing science or logic?
- Are the relationships and linkages clear and not redundant or overlapping?
- Is the applicability (geographic, technical) appropriate, unclear, or overstated? Applicability is appropriate.

Step 6: Implement the Model. Use of the Middle Potomac Watershed Model (Figure 2) involves the application of the watershed model to the subwatershed conditions, producing a subwatershed model, and then using the subwatershed model to identify potential ecosystem restoration projects. Figure 3 is the application of the watershed model to Cameron Run Watershed, VA. Documentation on Cameron Run conditions from the Reconnaissance Study was reviewed along with other information (summarized below) and the relevant drivers, stressors, EECs, and endpoints were identified and are shown in Figure 3. In the Recon Study, the Northern Virginia Potomac Subwatersheds are characterized as including the watersheds of the streams that are part of suburban Arlington and Alexandria, VA, Holmes Run, Backlick Run, Four Mile Run, Pimmit Run, Little Hunting Creek, and Indian Run (Fairfax County 2005). These watersheds collectively are managed as the Cameron Run Watershed (Fairfax County 2005). The population of the watershed in 2004 was 637,129. Restoration of conditions in Cameron Run is critical to the restoration of the Potomac and ultimately, critical to restoration of the Chesapeake Bay (USAE Baltimore 2004).

Conditions within the Cameron Run Watershed include:

Opportunities:

- Watershed Plan in place (Fairfax County 2005).
- Biodiversity documentation to inform aquatic and terrestrial restoration efforts (NBII 2003).

Problems:

- Loss of riparian and floodplain areas due to development in the Cameron Run watershed has resulted in 151.2 miles of streams that lack the recommended 100-ft riparian buffer for the Chesapeake (USAE Baltimore 2004).

- Degraded water quality – The Tributary Strategies (Commonwealth of Virginia 2005) in response to Chesapeake Bay Program and Stream Water Quality Report for Fairfax County have identified water quality problems.
- Degraded Habitat Conditions – Two Fairfax County assessments evaluated watershed conditions that affect habitat. These are the Stream Protection Strategy (SPS) and the Stream Physical Assessment (SPA) (Fairfax County 2005). The riparian (e.g., buffer) and aquatic components were considered separately in the assessments and are discussed separately here.
    - Degraded Terrestrial and Riparian Habitat
        - SPS evaluated vegetation and other watershed features on 10 parameters, and calculated overall percent impervious cover (Table 2-4 in Fairfax County (2005)). The SPS classified Cameron Run as a Watershed Restoration II Area. The goal of that category is to maintain areas to prevent further degradation and to take active measures to improve water quality to comply with regulations (Fairfax County 2005).
        - SPA evaluated habitat conditions and impacts on the stream from specific infrastructure and problem areas (Table 2-5 in Fairfax County 2005). Cameron Run Watershed is one of the poorest watersheds in Fairfax County from a habitat standpoint. Approximately 6 miles of stream were categorized as having “very poor” habitat conditions, 23 miles as “poor,” 17 miles as “fair,” and 2 miles as “good.” Cameron Run has few adequate riparian buffers, with more than 40 acres of deficient buffer per 10 miles (Fairfax County 2005).
    - Degraded Aquatic Habitat
        - For aquatic habitat, the SPS used an Index of Biotic Integrity (IBI), of benthic macroinvertebrates, community integrity, and a fish taxa richness (number of species present) measure.
        - For aquatic habitat, the SPA evaluated general stream characteristics and geomorphic classification of stream type.

What is the target condition or conditions? The above endpoints or target conditions assume that current efforts to attain Nitrogen, Phosphorous, and sediment limits will be attained. Gains in riparian and instream habitat are dependent on the water quality objectives. For Cameron Run, desired conditions are:

1. Stabilized riparian area and streambank to increase use by avian and other terrestrial groups (NBII 2003).
2. Stable instream aquatic habitat structure to increase use by macroinvertebrate, fish, amphibian, and reptile groups (NBII 2003).
3. Water quantity to support water supply demands (USACE Baltimore 2004).
4. Water quality to meet requirements of the Tributary Strategies and Chesapeake Bay Program.

These target conditions are the endpoints for the Cameron Run model (Figure 8).

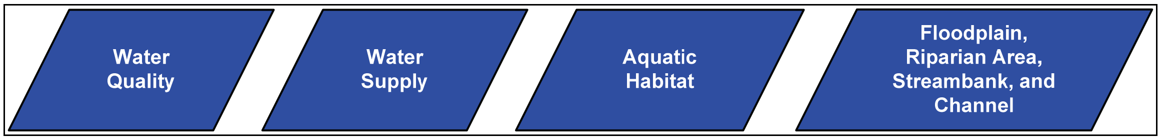

Figure 8. Endpoints for Cameron Run Watershed

How should the changes be organized, i.e., what are the EECs? For Cameron Run, significant resources are:

1. *Freshwater Quantity and Quality.* This is significant because of Cameron Run's contribution to the Potomac restoration, inextricably connected to the Chesapeake Bay restoration. For the gains in water quality to be sustained, the freshwater quantity and quality of Cameron Run and the Potomac River must be ensured.
2. *Terrestrial (Riparian) and Aquatic Habitat.* The SPS and SPA evaluations of aquatic and terrestrial habitat identified the risks to habitat (Fairfax County 2005). Biodiversity in urban areas has been highly impacted due to development. Cameron Run Watershed activities have the opportunity to improve the species abundance and richness. Restoration of aquatic habitat in Cameron Run supports the increase in biotic productivity in the Chesapeake Bay.

Three EECs hve been identified, the Terrestrial Habitat evaluated in the SPS and SPA analyses is represented as Floodplain, Riparian, and Streambank Resources, a broader characterization. The Cameron Run EECs are then:

- Floodplain, Riparian, and Streambank Resources.
- Aquatic Habitat.
- Freshwater Quantity and Quality.

What forces or drivers form the Cameron Run Watershed? In looking at Cameron Run (Figure 3), the drivers of the watershed are similar to the Middle Potomac Watershed (Figure 9).

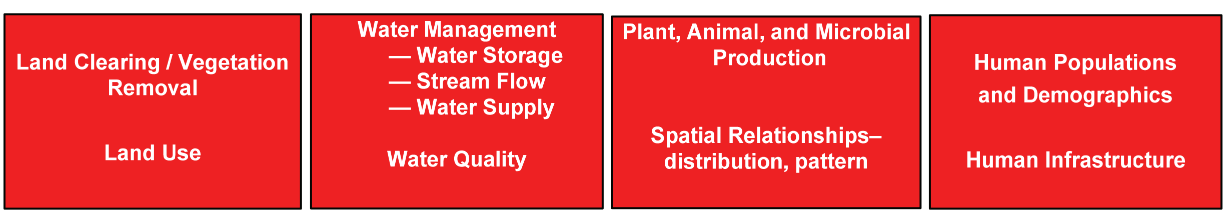

Figure 9. Drivers for Cameron Run Watershed

What are the relationships, interactions, and processes affecting the target condition? For Cameron Run, the stressors are similar to the stressors for the Potomac watershed (Figure 3). Differences are in the magnitude or importance of the different stressors. For Cameron Run, the intense urbanization (Socioculture Drivers) of the watershed compounds the changes deriving from the Hyrdosphere and Pedosphere Drivers and exacerbates the losses of the Biosphere Driver.

How Should the Changes be Organized, i.e., what are the EECs? Organization of the changes into categories of resources is shown in Figure 10:

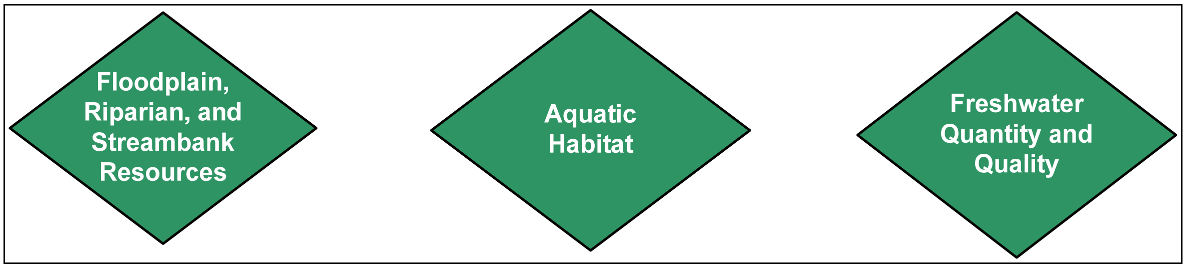

Figure 10. EECs for Cameron Run

As noted, the SPS and SPA reports evaluated both terrestrial and aquatic habitat components, using separate measures for floodplain and riparian habitat and aquatic habitat. Separation of aquatic from terrestrial resources in the EEC responds to the policies and responsibilities of Federal and local agencies. This should assist in identification of projects for Cameron Run.

IDENTIFYING ECOSYSTEM RESTORATION PROJECTS

The drivers, stressors, EECs and endpoints in the Cameron Run conceptual model serve to explain the production of the system endpoints, the target conditions desired from a functioning, healthy ecosystem. The endpoints—water quality, water supply, aquatic habitat, and floodplain and channel resources—are the objectives, the target conditions of projects undertaken by Federal, State, local, intergovernmental and private efforts. The interrelationships of sediments, water, biota, and system processes in the endpoints are undeniable. Aquatic Habitat is not possible if water quality is unsuitable, for instance. Agency responsibilities and authorities are formulated so that an agency's projects focus on the expertise, responsibilities, and authorities of that agency. For the Corps, this means that ecosystem restoration is focused on restoring hydrologic processes and aquatic habitat. This leads the Corps planner to ask "how far up the bank (or "how far upland") can we go in restoration. Floodplain and riparian restoration, critical to stream stability, must be closely related or integral to the success of the aquatic restoration.

The Potomac and Cameron Run watersheds are typical of most in the United States, human use and urbanization have resulted in land development, degradation of riparian areas, and loss of aquatic habitat. For Cameron Run, these conditions have been extensively documented in the Cameron Run Watershed Plan (Fairfax County, Chap. 4 (2005)). Problems and opportunities were identified on a subwatershed basis, listing the type, location and extent of the problem. The problems and potential solutions were reviewed by the authors and each problem categorized them into five different project categories (Table 10).

Table 10. Classification of Projects Identified by Watershed Plan (Fairfax County (2005))

Project Category	Management Measures
Aquatic Restoration	Channel redesign to remove effects of channelization - variously called dechannelization or natural channel design Streambed stabilization Channel sediment removal Instream plantings
Maintenance Actions	"Natural" (low impact) maintenance Exotics removal
Restoration of Riparian and Floodplain Integrity	Stormwater management- retention ponds Wetland restoration Removal of dumpsites
Infrastructure Operation	Trash cleanup Sewer repair Salt staging area maintenance
Water Quality	Control of pollution from residences Bacterial pollution Abandoned site runoff
Recreation Resources	Local park management or development Recreation and aesthetic features to integrate with stream project

Ecosystem Restoration Projects — Channel and Streambank Restoration. All of the eight subwatersheds identified problems with the channel, resulting from previous channelization projects, streambed instability, and streambank instability. Restoration of the structural integrity of the channel and streambanks is required to prevent further degradation of the aquatic ecosystem. Many components of this restoration are identified in the watershed plan (Fairfax Co. Chap. 6 2005). This restoration would promote colonization of aquatic fauna and development of complex, mature aquatic communities. The authority to undertake the restoration is within two of the Corps' legal authorities: Sec.206 Aquatic Ecosystem Restoration and Sec. 1135 Project Modifications for Improvement of the Environment.

What About the Other Endpoints? The recommended aquatic restoration project will benefit the Aquatic Habitat endpoint. The ability to incorporate management measures to address the other endpoints (Water Supply, Water Quality, Terrestrial Habitat) in a Corps project is dependent in part on identifying the link to aquatic restoration or aquatic habitat. That is, there must be a link of a proposed measure to the Corps' authority to restore hydrology and aquatic ecosystems.

- *Maintenance Actions.* Maintenance of the streambank and channel can be accomplished through low impact, minimal disturbance maintenance actions, usually labor intensive. Since maintenance is part of the local sponsors' responsibilities, this could be included as a project measure. Maintenance actions affect all of the endpoints.
- *Restoration of Riparian and Floodplain Integrity.* These projects can increase the benefits of aquatic restoration by retaining water for runoff attenuation, infiltration, wetland functions and providing riparian services – terrestrial habitat, edge effect, water quality. For

incorporation into an aquatic restoration project, the contribution and connection of the riparian and floodplain areas should be clear, that is, the aquatic benefits would be diminished without the riparian component. This is the "how far do we go up the bank" issue mentioned above. Riparian and Floodplain Integrity measures affect Water Supply and Floodplain, Riparian, Streambank and Channel endpoints.

- *Infrastructure Operation.* Responsibility for sewer, refuse, and transportation support (e.g., salt staging) are local non-federal responsibilities and, unless part of a riparian area included in the project, would not be part of a Corps aquatic restoration project. These infrastructure considerations may be integral to EPA or other water quality efforts.
- *Water Quality.* Pollutants and contaminated runoff can destroy aquatic habitat, but water quality management is within the purview of the state and local water quality agencies. The efforts to improve the Chesapeake Bay water quality implemented the nutrient and sediment loading standards (Commonwealth of Virginia 2005).
- *Recreation Resources.* The public benefit of aquatic restoration is enhanced by the access in the form of parks and trails. These projects are the responsibility of local cost-sharers and not a requirement for restoration.

Observations on the Model Application.

- In developing the Middle Potomac and Cameron Run models, the model descriptor categories (Henderson and O'Neil 2007) were readily used to identify the appropriate parameters for the models. In using the Recon Study information to identify the components, drivers for the model were identified from the template driver categories. Identifying stressors and endpoints required some discussion and refinement to fit the conditions of the Middle Potomac. The component categories thus served to focus the discussion rather than provide a menu to pick endpoints and stressors.
- The Middle Potomac model meets the requirements for its stated objectives and use, i.e., objectives of identifying cause-effect relationships and organizing system components; model use as an organizational framework for development of subwatershed models. The use for identifying ecosystem restoration projects influences the construction of the model, so that other programmatic or functional projects are not as prominent. For instance, meeting the water quality requirements of the Tributary Strategies could require extensive management, land use, and operational changes. At least on a subwatershed basis, meeting the water quality objectives could affect (improve or constrain) ecosystem restoration. That effect is not evident in the present formulation of the model. The interaction of water quality and restoration would be more important for communication, that is, if the objective of the model were communication. These kinds of questions could be addressed in model development by clarity in terminology. A minimum description and definition on the understanding and limits of each of the components would be helpful.
- At the time of tech note preparation, the Middle Potomac and Cameron Run models were under review, so it is difficult to evaluate performance of use of the model. As model use is undertaken, the following will guide evaluation (Henderson and O'Neil 2004):
    - Did the specification of drivers and stressors closely match the management measures or alternative components?
    - Are there links or pathways of driver: stressor or endpoint: stressor relationships that were not affected? Is there a possibility that the links are not important?

- Is there redundancy in the response of drivers, stressors, or endpoints? Does combining two or more make sense?
- Does the evaluation of endpoint changes make sense and provide decision-making or guidance capability?

The answers to these questions will provide indications of possible revisions to the model.

SUMMARY: Development of the Middle Potomac Conceptual Model followed guidance of the six steps outlined in Henderson and O'Neil (2005), and model descriptor selection (Henderson and O'Neil 2007), and component specification. The six-step process resulted in careful and deliberate preparation of the models. Further refinement or revision to the process, descriptors, and components will occur as further models are developed.

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APPENDIX A

Interaction Matrices and Simplified Models Diagrams. This appendix contains the interaction matrices used for Step 4: Identify the Sources of Change in the System, part of the six-step conceptual model construction process. Due to comprehensiveness and complexity of the systems, Figures 2 and 3 in the main text caused reviewers to request a simplified version. To simplify the graphic representation, the nine stressor categories were used, rather than the 16 individual stressors.

Interaction Matrices. Interaction matrices are one way to identify the relationships between the components of the conceptual models. As with other applications of these matrices, the component items are arrayed across the columns of a table and down the rows. For the conceptual models, three successive matrices are used:

- Drivers: Stressors.
- Stressors: EEC.
- EEC: Endpoints.

Table A1 is the Driver: Stressor matrix for the Middle Potomac Conceptual Model. For each driver the cells in the matrix indicate:

- Stressors resulting from that driver.
- Stressors affected by that driver.

For instance, the Driver Land Clearing/Vegetation Removal results in changes in the Stressor Categories Landform and Sediment, and affects, influences, or contributes to the Stressor Categories of Water Quantity, Water Quality; Biotic Composition, Biotic Structure, and Biotic Processes; and Human Phenomenon and Human Infrastructure.

Note that the Water Management Drivers (Storage, Stream Flow, and Supply) are included separately in the matrix, but are not shown separately on the figures. Table A2 is the Stressor: EEC matrix for the Middle Potomac Conceptual Model. The EEC construct is used to organize all of the stressor changes into broad categories that assist in identifying affected endpoints and help in understanding the system. Table A3 is the EEC: Endpoint matrix for the Middle Potomac Conceptual Model. The relationship and interconnectedness of the EECs to endpoints is shown. Tables A4 through A6 are the interaction matrices for the Cameron Run Conceptual Model.

Simplified Models. Reviewers of previous drafts of this technical note suggested including simplified versions of the Microsoft Visio™ conceptual models shown in Figures 2 and 3 in the main text. The PowerPoint™ conceptual models of the Middle Potomac and Cameron Run (Figures A1 and A2, respectively) were simplified by using only the stressor categories and not including all of the stressors. The interactions identified in the tables were used to establish the connections among the drivers, stressor categories, EECs, and endpoints. The reader can trace out the interactions identified in the matrices on Figures A1 and A2.

Table A1. Driver: Stressor Interaction Matrix for Middle Potomac Conceptual Model

	Drivers										
Stressors	Land Clearing / Veg Removal	Land Use	Water Management - Storage	Water Management Stream Flow	Water Management - Water Supply	Water Quality	Plant, Animal, and Microbial Production	Nutrient Cycling	Spatial Relationships	Human Populations and Demographics	Human Infrastructure
Landform											
Sediment											
Water Quantity											
Water Quality											
Biotic Composition											
Biotic Structure											
Biotic Process											
Human Phenomenon (Process)											
Human Infrastructure											

Table A2. Stressor: EEC Interaction Matrix for Middle Potomac Conceptual Model

	Stressors								
EEC	Landform	Sediment	Water Quantity	Water Quality	Biotic Composition	Biotic Structure	Biotic Process	Human Phenomenon (Process)	Human Infrastructure
Floodplain, Riparian, and Streambank Resources									
Aquatic Habitat									
Freshwater Quantity and Quality									

Table A3. EEC Endpoint Interaction Matrix for Middle Potomac Conceptual Model

	EEC		
Endpoints	Floodplain, Riparian, and Streambank Resources	Aquatic Habitat	Freshwater Quantity and Quality
Runoff Storage and Retention			
Water Supply			
Water Quality			
Aquatic Habitat			
Floodplain, Riparian Area, Streambank, and Channel			

Table A4. Driver: Stressor Interaction Matrix for Cameron Run Conceptual Model

Stressors	Drivers									
	Land Clearing / Veg Removal	LAND USE	Water Management - Storage	Water Management Stream Flow	Water Management - Water Supply	Water Quality	Plant, Animal, and Microbial Production	Spatial Relationships	Human Populations and Demographics	Human Infrastructure
Landform										
Sediment										
Water Quantity										
Water Quality										
Biotic Composition										
Biotic Structure										
Biotic Process										
Human Phenomenon (Process)										
Human Infrastructure										

Table A5. Stressor: EEC Interaction Matrix for Cameron Run Conceptual Model									
	Stressors								
EEC	Landform	Sediment	Water Quantity	Water Quality	Biotic Composition	Biotic Structure	Biotic Process	Human Phenomenon (Process)	Human Infrastructure
Floodplain, Riparian, and Streambank Resources									
Aquatic Habitat									
Freshwater Quantity and Quality									

Table A6. EEC: Endpoint Interaction Matrix for Cameron Run Conceptual Model			
	Endpoints		
EEC	Floodplain, Riparian, and Streambank Resources	Aquatic Habitat	Freshwater Quantity and Quality
Water Quality			
Water Supply			
Aquatic Habitat			
Floodplain, Riparian Area, Streambank, and Channel			

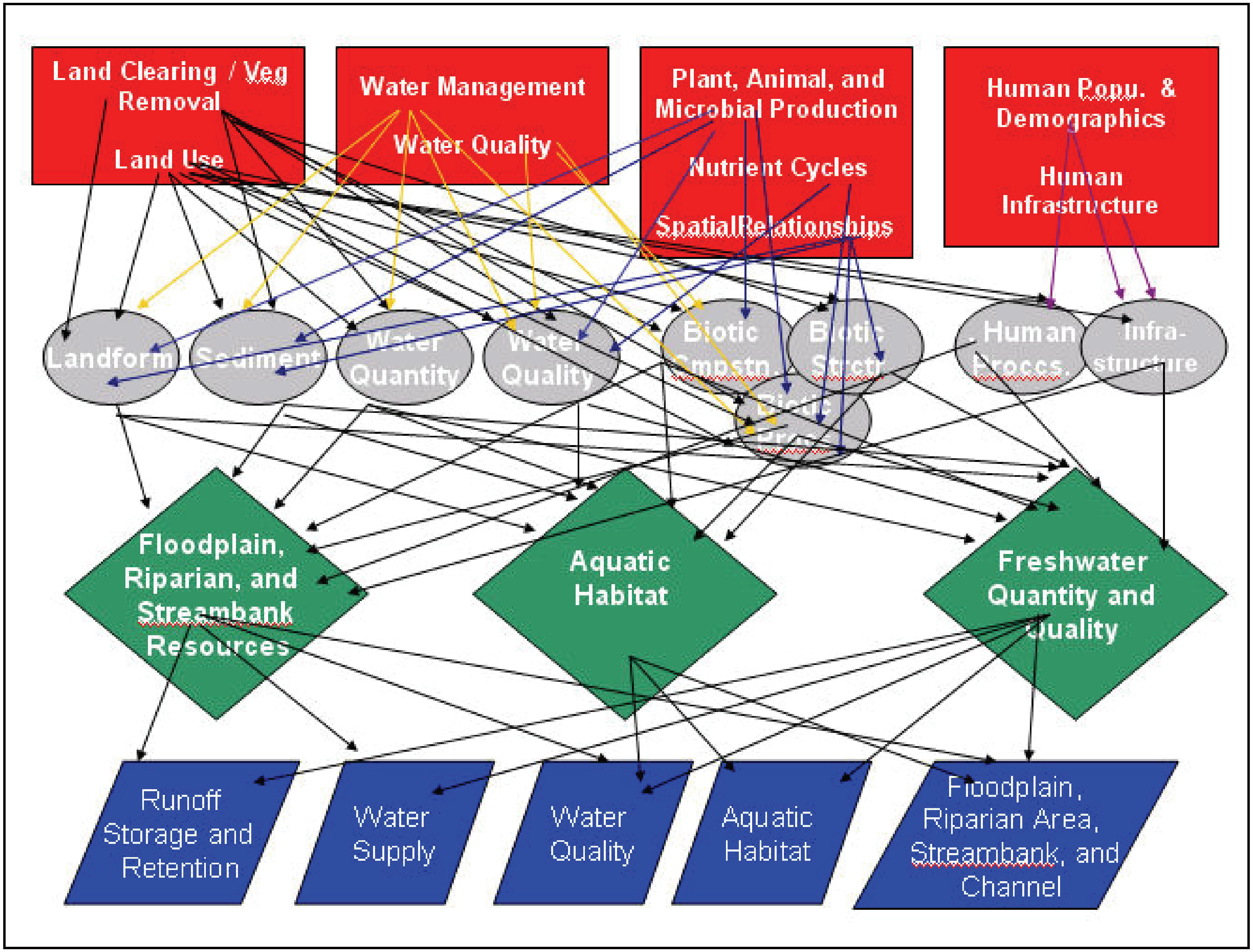

Figure A1. Middle Potomac Conceptual Model

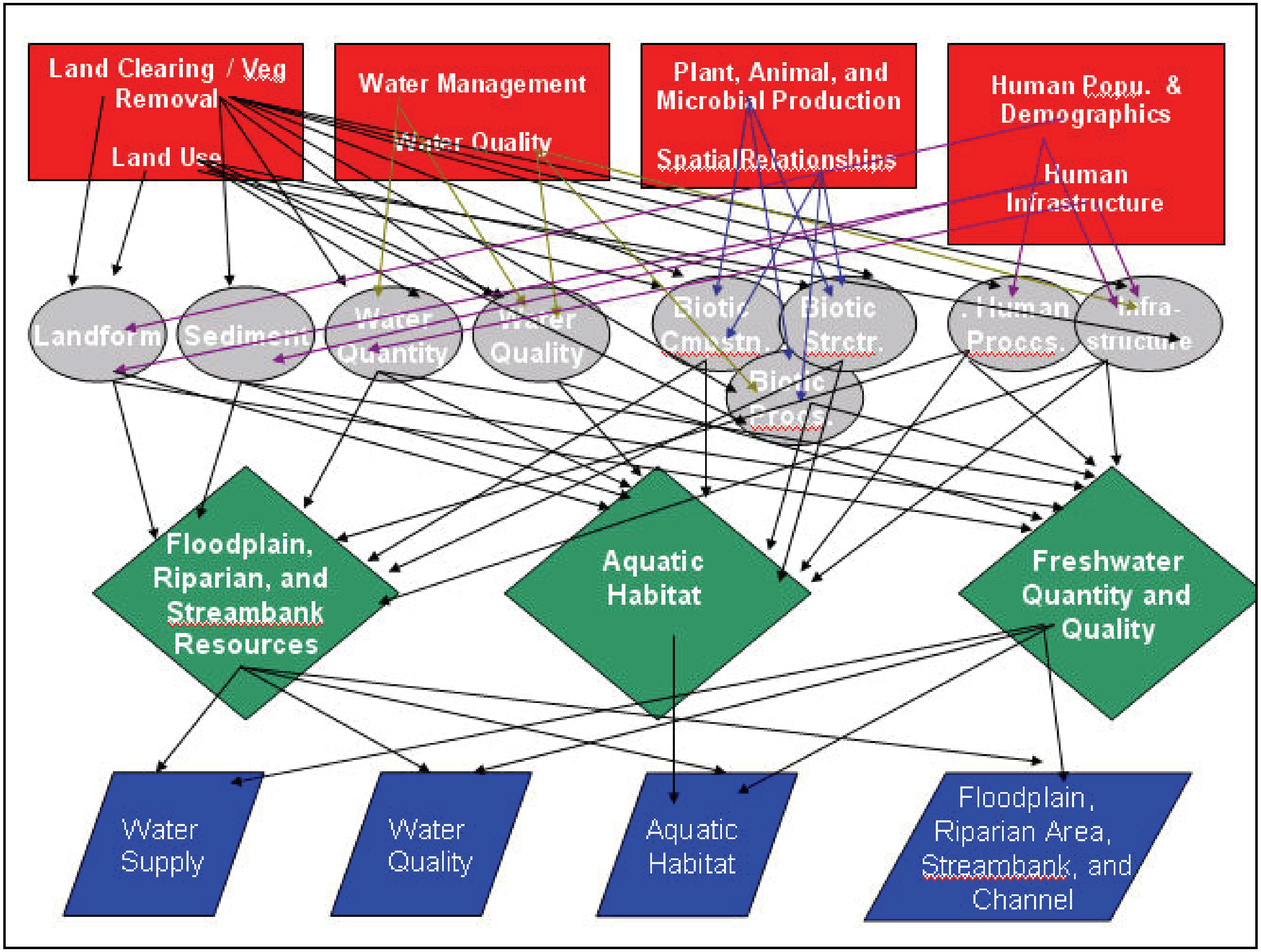

Figure A2. Cameron Run Conceptual Model